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CABIN HAZARDS FROM A LARGE EXTERNAL FUEL FIRE ADJACENT TO AN AIRCRAFT FUSELAGE

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AUGUST 1979

FINAL REPORT

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16. Abstract

Fourteen fire tests were conducted with a surplus, fire-hardened DC7 fuselage positioned adjacent to a 20-foot-square JP-4 fuel fire. The fuselage had a door opening at the center of the fire and door openings displaced from the fire on each side of the fuselage. Temperatures, light transmittances, and heat fluxes were measured for each of these 90-second tests. The opening of doors away from the fire was varied from test to test as was the ambient wind velocity. Wind direction coupled with the door opening configuration were found to be controlling factors in the accumulation of heat and smoke within the aircraft cabin. Heat fluxes into the cabin through the fire door also changed significantly with wind and door openings and depended on the degree of flame penetration through the fire door. When flames did not penetrate into the cabin, the symmetry plane heat flux at the fire door station agreed very well with earlier modeling predictions.

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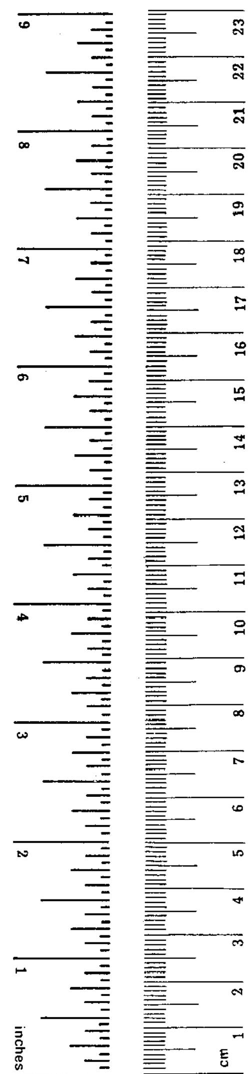
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

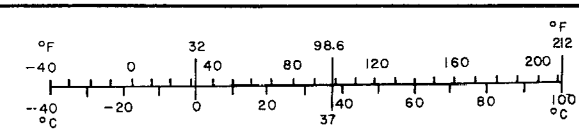
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The assistance of Messrs. Joseph A Wright, Franklin D. Fann, and Lawrence J. Curran in the varying activities of instrumentation, testing, and data analysis is acknowledged. The helpful advice of and useful discussions with Dr. Thor Eklund are also acknowledged.

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INTRODUCTION

PURPOSE.

The purpose of this project was to measure and study the flame penetration and resulting accumulation of heat and smoke inside an aircraft cabin produced by a large external fuel fire adjacent to a fuselage door opening.

BACKGROUND.

During an impact-survivable crash, the cabin interior can be threatened by a possible external fuel fire. Heat, smoke, and toxic gases may enter the cabin through fuselage openings and create hazardous conditions within a short period of time (reference 1).

Full-scale tests on the effect of large pool fires on a fuselage have produced heat transfer rates to the exterior as high as 13 British thermal units per foot squared second (Btu/ft^{2}s) (reference 2) in one set of tests, 16 Btu/ft^{2}s in another (reference 3), and 18 Btu/ft^{2}s in tests on a titanium fuselage (reference 4). These heat fluxes are upper extremes that can be realized from a large fuel fire. Wind conditions, door opening configurations, breaks in the fuselage, or "burn-throughs" can be expected to cause great variability in the cabin hazard levels. The cabin hazards resulting from a small fuel fire adjacent to an intact fuselage door opening have been more recently studied at the National Aviation Facilities Experimental Center (NAFEC) in full-scale C133 tests (reference 1). Physical fire modeling tests were also performed to examine the C133 cabin environment under large fuel fire conditions (reference 5). A full-scale test as reported herein was needed to confirm and validate heat and smoke measurements obtained in other modeling and small-scale tests.

EXPERIMENTAL OBJECTIVE.

The experimental objective of this project was to conduct full-scale tests to study the effect of large external pool fires adjacent to an aircraft fuselage door opening.

DISCUSSION

GENERAL APPROACH.

Tests were performed at NAFEC's airport fire test site utilizing an existing 400-ft^2 fire pit. A stripped-out, surplus DC7 fuselage (previously first used by Marcy (reference 6) for aircraft interior materials testing) was prepared as a test article (figure 1). To preserve the aluminum fuselage for more than one test, the aircraft skin was "fire-hardened" with galvanized steel sheeting (0.032 inches thick) placed over Kaowool® noncombustible aluminosilicate fiber blankets (1 inch thick). The fire hardening extended 20 feet on either side of the fire doorway from the top to the bottom centerlines of the fuselage. Two additional doorways were cut on each side of the fuselage approximately 30 feet forward of the fire doorway. These doorways were fitted with removable metal covers. This was accomplished for the purpose of varying the door opening configuration from test to test. All three doorways measured 28 inches wide by 56 inches high. These door dimensions properly scale the Type A doorway openings in the C133 (76 inches by 42 inches) and fire modeling

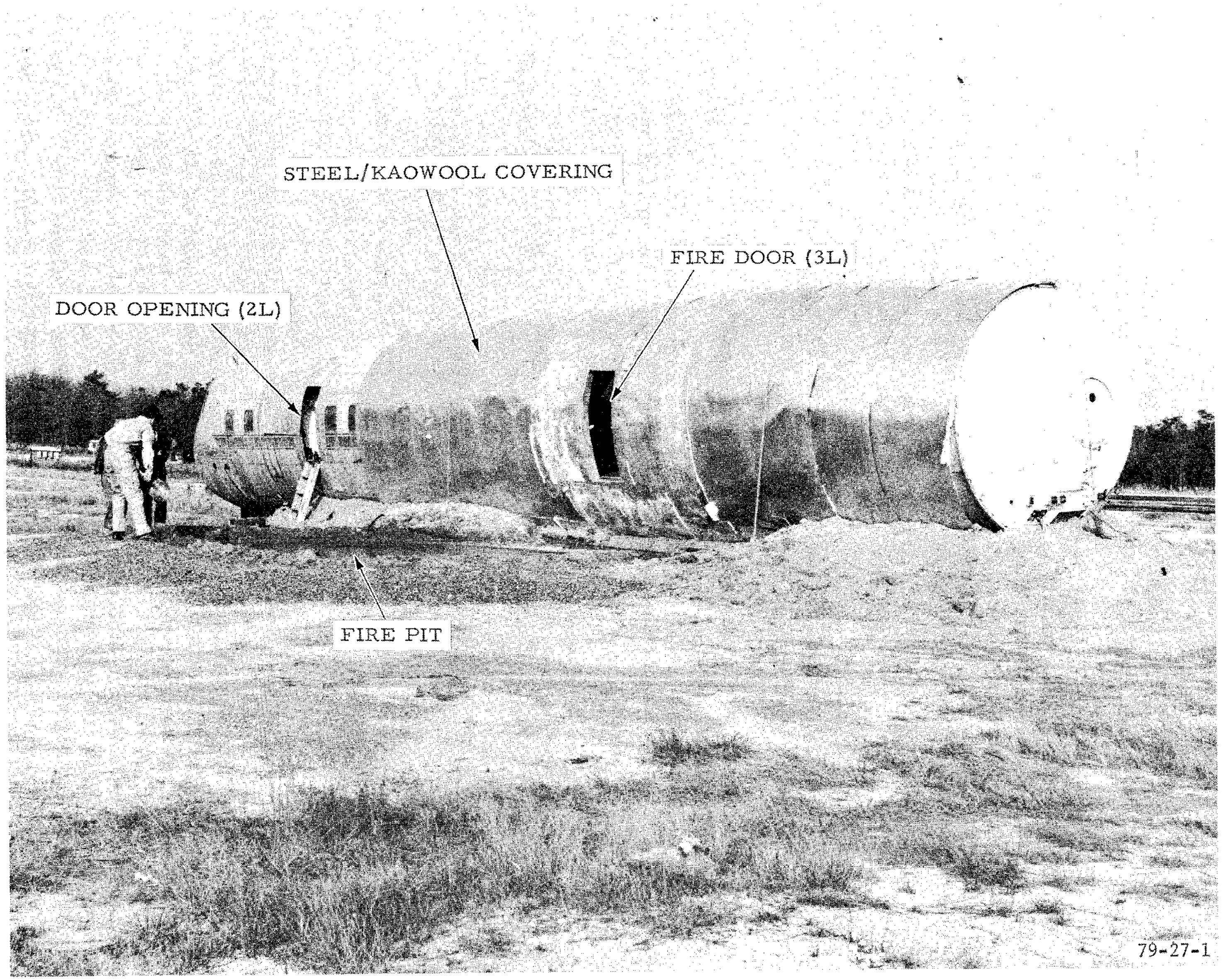

FIGURE 1. FIRE-HARDENED FUSELAGE

(19 inches by 10.5 inches) test articles. The interior was fire-hardened to varying degrees (depending on the proximity to the fire door) using Kaowool, fiberglass cloth, galvanized and stainless steel sheets, and transite. Extra effort went into stripping out combustible materials (insulation, hatracks, etc.) especially on the fire side of the fuselage. The test article was positioned with the fire doorway at the center of one side of the firepit (figures 1 and 3).

INSTRUMENTATION.

Instrumentation consisted of calorimeters, thermocouple trees, laser transmissometers, motion picture and still photography, and a windspeed and direction indicator. Laser transmissometer, windspeed, and calorimeter data were recorded on a Honeywell model 1858 oscillograph. Thermocouple data were recorded on an Esterline Angus model D2020 digital data logger. Both recorders were located in an instrumentation trailer near the fuselage. Plan and side views of the cabin interior show calorimeter, thermocouple, and laser transmissometer locations (figure 3). Three calorimeters (Hy-cal model C-1300-A) were installed at locations that correspond to those of the C133 and physical fire modeling test articles. These locations include the ceiling (C2), exterior skin (C3) (adjacent to the fire doorway), and the symmetry plane of the doorway (C1) (figures 2 and 3). Two thermocouple trees, each consisting of four chromel-alumel thermocouples, were used to record temperatures within the cabin. Two helium-neon laser transmissometers were mounted horizontally at different heights to span a 3-foot cross-section of the cabin (L1 top and L2 bottom). The lasers (Spectra Physics model 155, wavelength = 632.8 nanometers) and photocells (Weston model 856 YR) were covered with fiberglass cloth over Kaowool blankets for protection from the harsh environment (figure 4). A Trade-Wind cup anemometer (model 110) was positioned next to the instrumentation trailer and used to record wind velocities continuously on the oscillograph. Wind direction was manually recorded from a Taylor Windscope (model 3105) direction indicator. Four motion picture cameras were used to document the tests.

TEST PROCEDURE.

A set routine was followed in preparing for and conducting each test. The fire pit was first filled with water to a depth that sufficiently covered the gravel bed. One hundred gallons of JP-4 fuel was pumped from a fuel tanker truck into the pit. Calorimeter cooling lines were checked for proper water flow and laser transmissometer windows were cleaned.

Calibration checks were performed on the oscillograph and thermocouple recorders. Firemen prepared for extinguishing the fire. With all instruments operational, a signal was given to first start the motion picture cameras and then to light the fire pit with a torch. Test duration was 90 seconds, at which time a signal was given for the firemen to extinguish the fire using light-water. Although a longer test duration may have been desirable, 90 seconds was adequate to allow for the development of cabin hazard level conditions reflecting wind and door opening configurations and was believed not to unduly jeopardize the test article. The fire pit was then pumped out to prepare for another test. Repeated early morning tests were

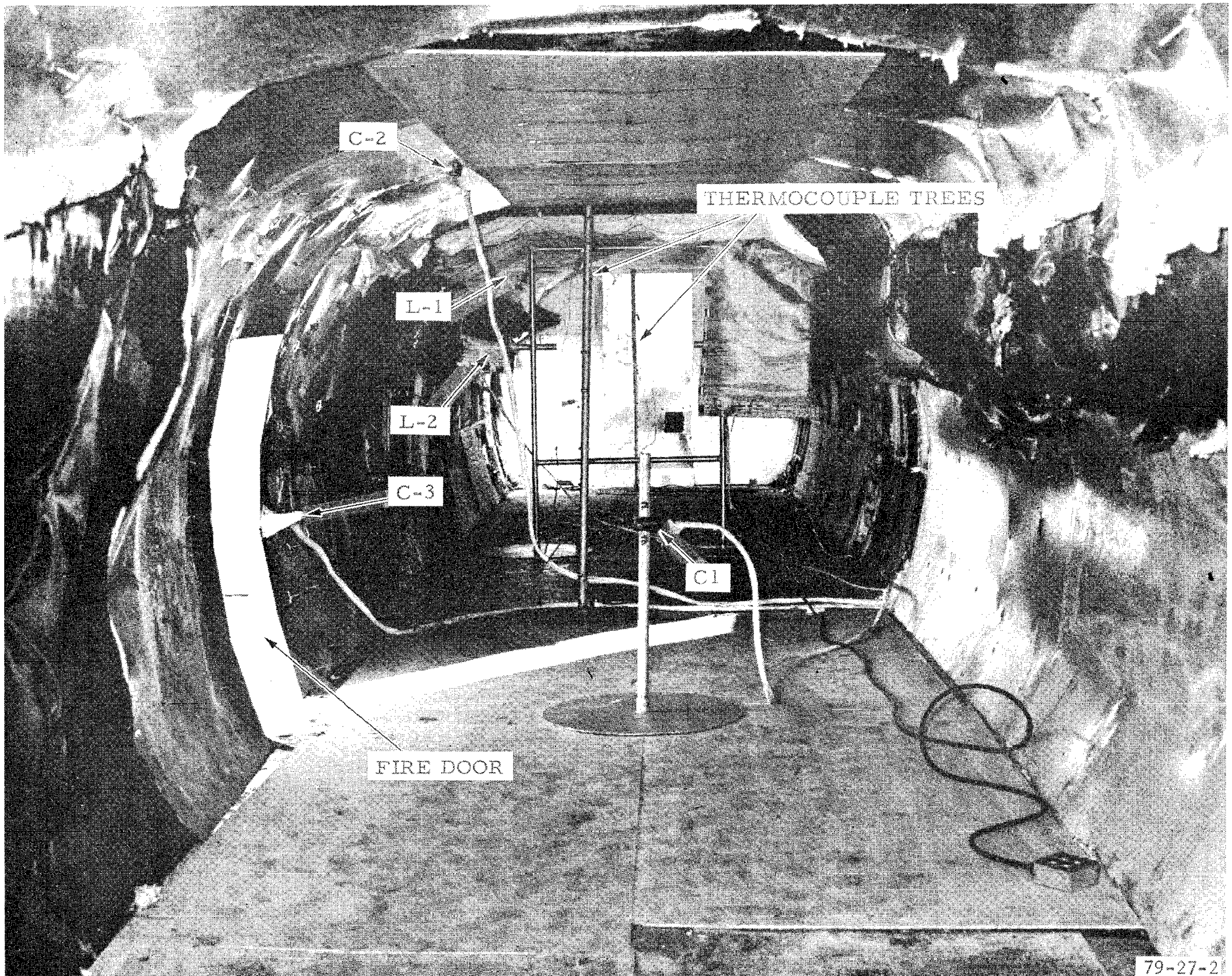

FIGURE 2. FORWARD VIEW OF DC7 INTERIOR

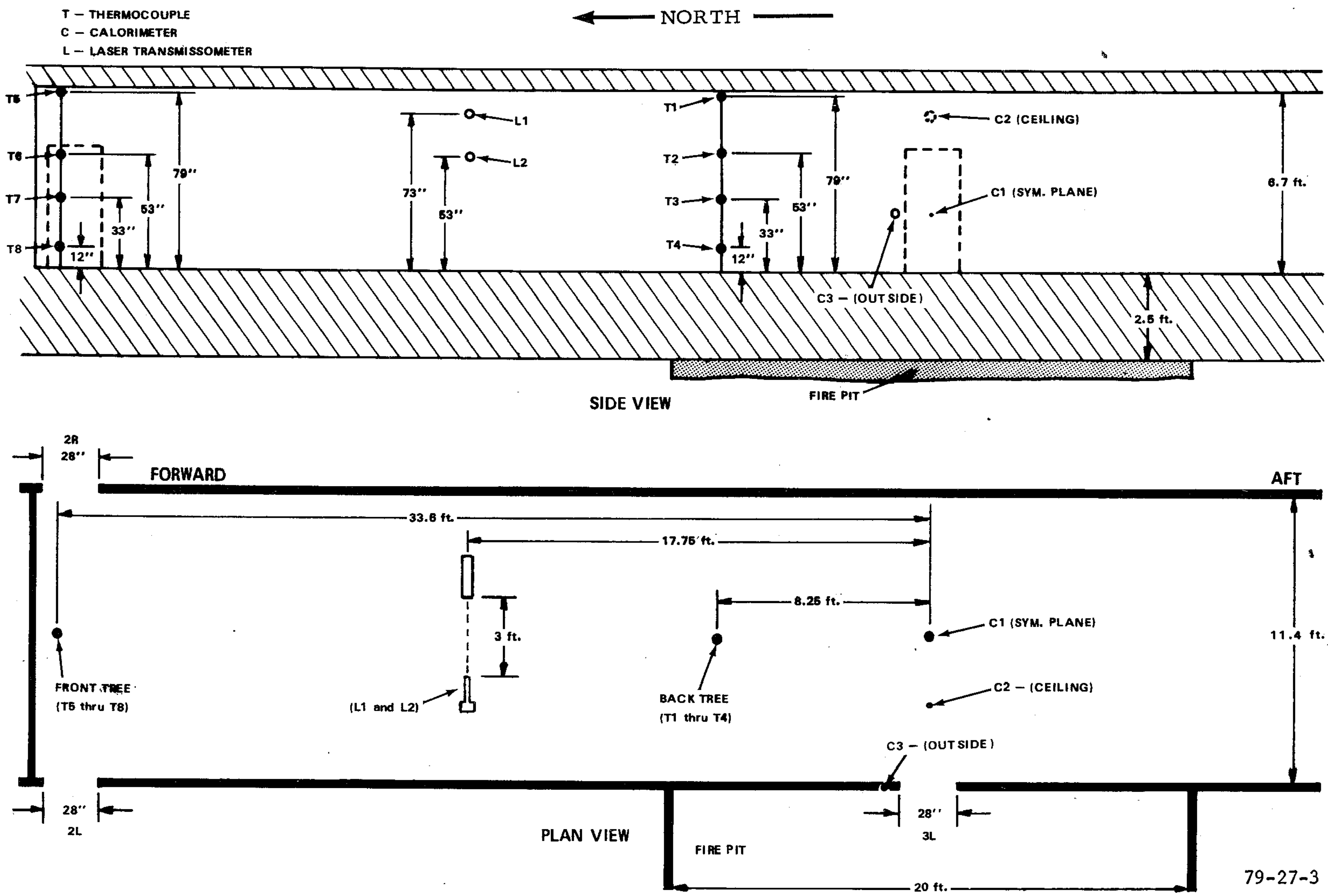

FIGURE 3. THERMOCOUPLE, CALORIMETER, AND LASER TRANSMISSOMETER LOCATIONS

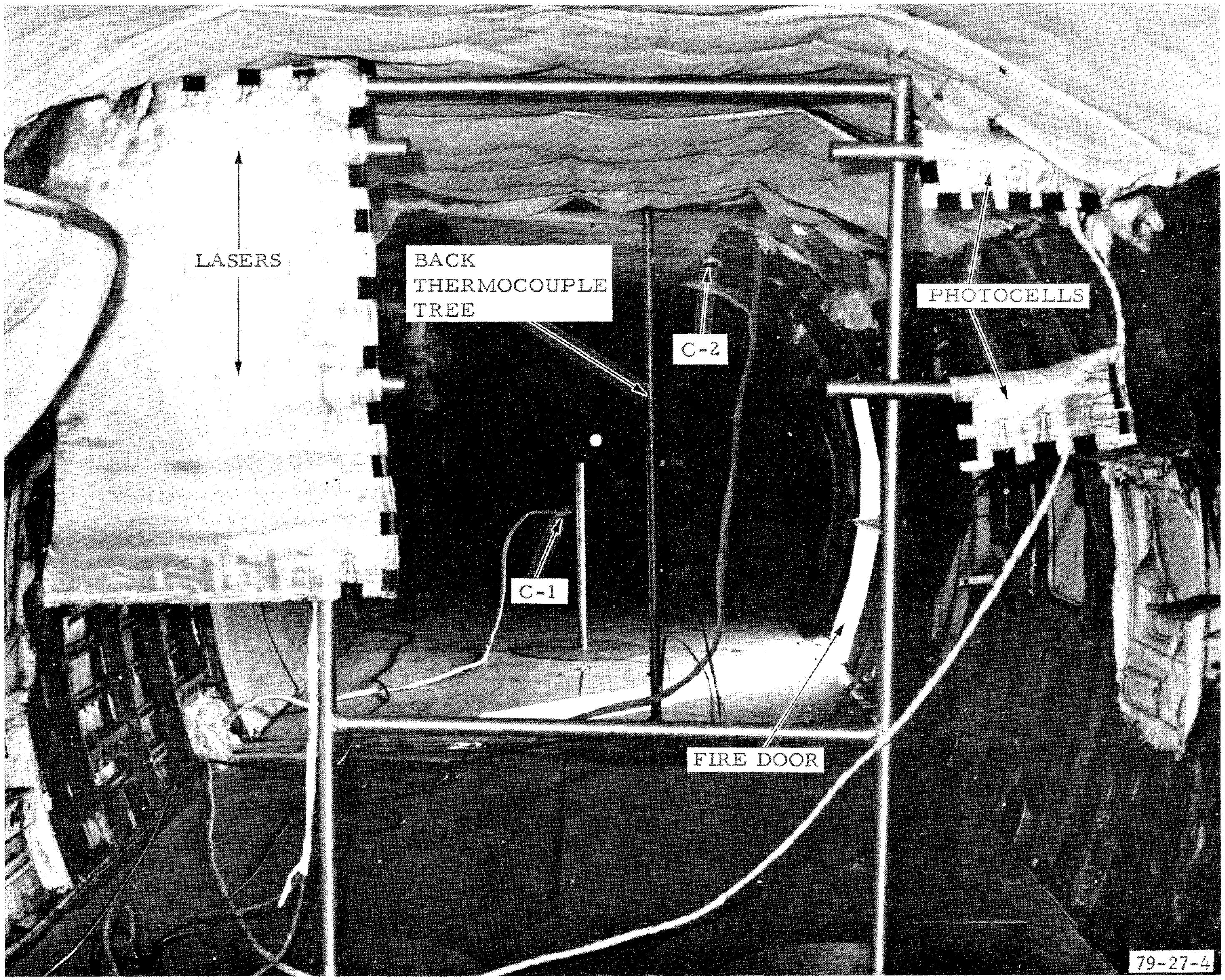

FIGURE 4. AFT VIEW OF DC7 INTERIOR

conducted in an attempt to obtain a calm (reference 7) wind condition (table 1) for baseline data.

TEST RESULTS AND ANALYSIS.

Table 2 summarizes the initial conditions of the 14 tests which were conducted during November 1978. In one category of tests, the cabin hazard levels were low compared to the remaining test results. These low results were obtained when the wind direction was parallel to the fuselage. Peak symmetry-plane heat flux was less than 1.2 Btu/ft^{2}s, and peak ceiling temperature at T1 (figure 3) was less than 200 degrees Fahrenheit (^oF). A test with the wind blowing the fire in a direction away from the fuselage (test 8) also produced low results similar to the parallel wind tests. It became clear from observers' tape recorded reports and exterior movie coverage that the fire doorway was visible during this category of tests, indicating that cabin exposure conditions were not representative of a realistic, large fire. Fuselage skin calorimeter (C_3) output averaged less than 5 Btu/ft^{2}s, thus confirming the low cabin environmental readings that were recorded for these tests.

The remaining tests, which produced significantly higher hazards, fall into two categories. One of these categories is the calm wind condition during which test 13 (all doors open (ADO)) and test 14 (all doors closed (ADC)) were conducted. Significant differences in heat accumulation for these two tests are apparent in the plot of the rear ceiling thermocouple's (T1) outputs (figure 5). Cabin temperature continued to increase when the doors were open, but leveled off at 50 seconds when the doors were closed. These same trends can be seen in the responses of the symmetry plane and ceiling calorimeters (figures 6 and 7, respectively) and the light transmittance data for the bottom laser transmissometer (see appendix A page A-3). It is evident from both photography (figure 8) and the ceiling calorimeter data that there was significant flame penetration during test 13. Smoke and heat filled the cabin and vented out of both forward doorways (figure 9). Test 14 experienced much less flame penetration, as evident in the ceiling calorimeter data (figure 7). Subsequently, less accumulation of heat and smoke occurred during test 14 as compared with test 13. A fire whirl (reference 8) developed during test 14 (figure 10) causing intense radiant heat to be felt by test personnel. However, skin calorimeter output at the fire door for test 14 showed that the fire whirl did not appear to have adversely affected the test results as compared with test 13.

A numerical integration was performed on the symmetry plane calorimeter plot for these two tests. The heat fluxes from 20 seconds (time when fire becomes fully developed) to 70 seconds (time when most readings began to dropoff) averaged 2.4 Btu/ft^{2}s and 1.8 Btu/ft^{2}s for tests 13 and 14, respectively. A heat flux of 1.8 Btu/ft^{2}s was obtained during modeling tests for an "infinite" fire under quiescent wind conditions (reference 5). A higher average symmetry plane heat flux for test 13 is attributed to the flame penetration documented during the test which was significantly greater than in test 14. The variation in door opening configuration appeared to be the controlling factor in these two tests.

TABLE 1. BEAUFORT WIND SCALE *

Windspeed mi/h	kn	Description	Observation
0-1	0-1	Calm	Smoke Rises Vertically
1-3	1-3	Light Air	Smoke Drifts Slowly
4-7	4-6	Slight Breeze	Leaves Rustle
8-12	7-10	Gentle Breeze	Leaves and Twigs in Motion
13-18	11-16	Moderate Breeze	Small Branches Move
19-24	17-21	Fresh Breeze	Small Trees Sway

* Beaufort wind scale is used because of its simple way in defining the minor variation in wind velocities encountered during testing (reference 7).

TABLE 2. SUMMARY OF TEST CONDITIONS

Test No.	Date	Time (EST)	Wind Condition (1)	Wind Direction (Degrees) (2)	Ambient Temperature (F)	Door Configuration (3) (4) (5)
1	11/15/78	0636	calm	---	57	ADO
2	11/15/78	1046	slight to gentle breeze	0	65	ADO
3	11/18/78	0950	moderate breeze	270	55	UDO (2R closed)
4	11/18/78	1249	gentle breeze	270	68	DDO (2L closed)
5	11/19/78	0655	light air	315	34	ADO
6	11/20/78	0621	light air	0	38	ADO
7	11/21/78	0623	slight breeze	0	41	ADO
8	11/21/78	1427	slight to gentle breeze	060	57	ADO
9	11/24/78	0621	slight to gentle breeze	270	56	ADO
10	11/24/78	1054	gentle to moderate breeze	270	64	ADC (2R and 2L closed)
11	11/26/78	0652	light air to slight breeze	0	34	ADO
12	11/28/78	1003	slight breeze	0	43	ADO
13	11/29/78	0630	calm	---	31	ADO
14	11/29/78	1406	calm to light air	270	49	ADC (2R and 2L closed)

1. Reference table 1
2. Aircraft nose heading north (0°)
3. See figure 3
4. Fire door (3L) open for all tests
5. ADO - All Doors Open
   UDO - Upwind Door Open
   DDO - Downwind Door Open
   ADC - All Doors Closed

-- Not applicable

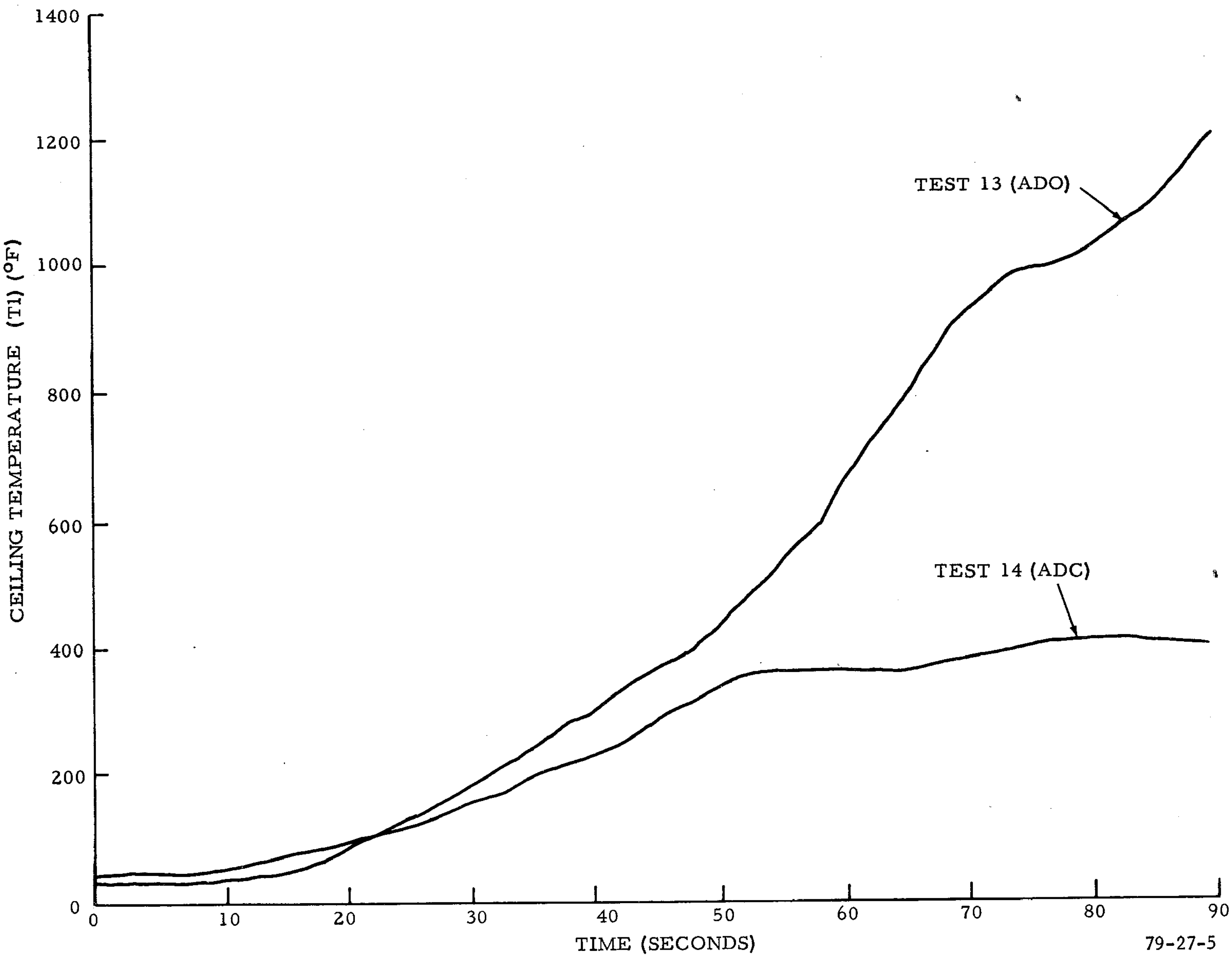

FIGURE 5. CEILING TEMPERATURE HISTORY UNDER CALM WIND CONDITIONS--TESTS 13 AND 14

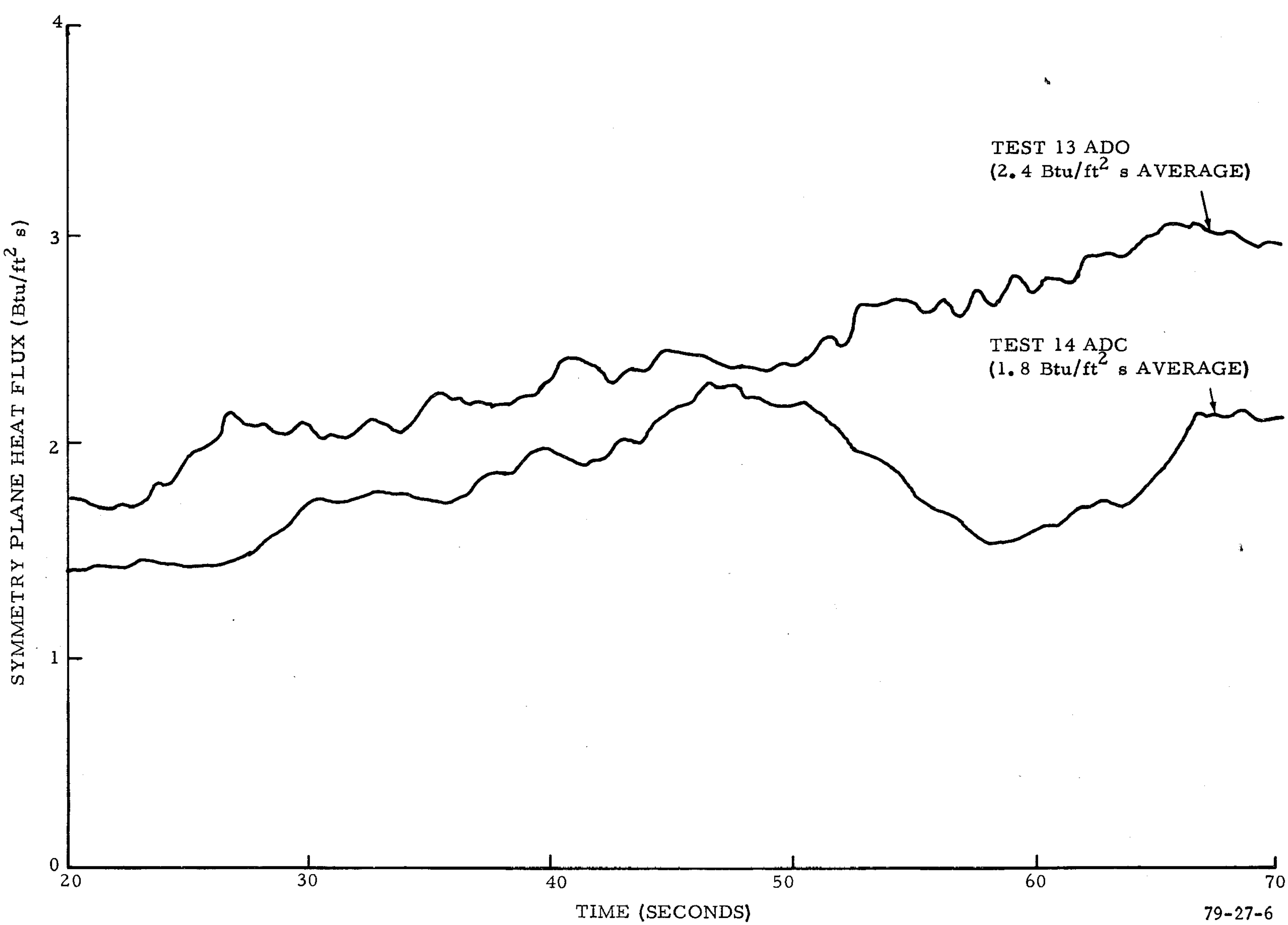

FIGURE 6. SYMMETRY PLANE HEAT FLUX UNDER CALM WIND CONDITIONS--TESTS 13 AND 14

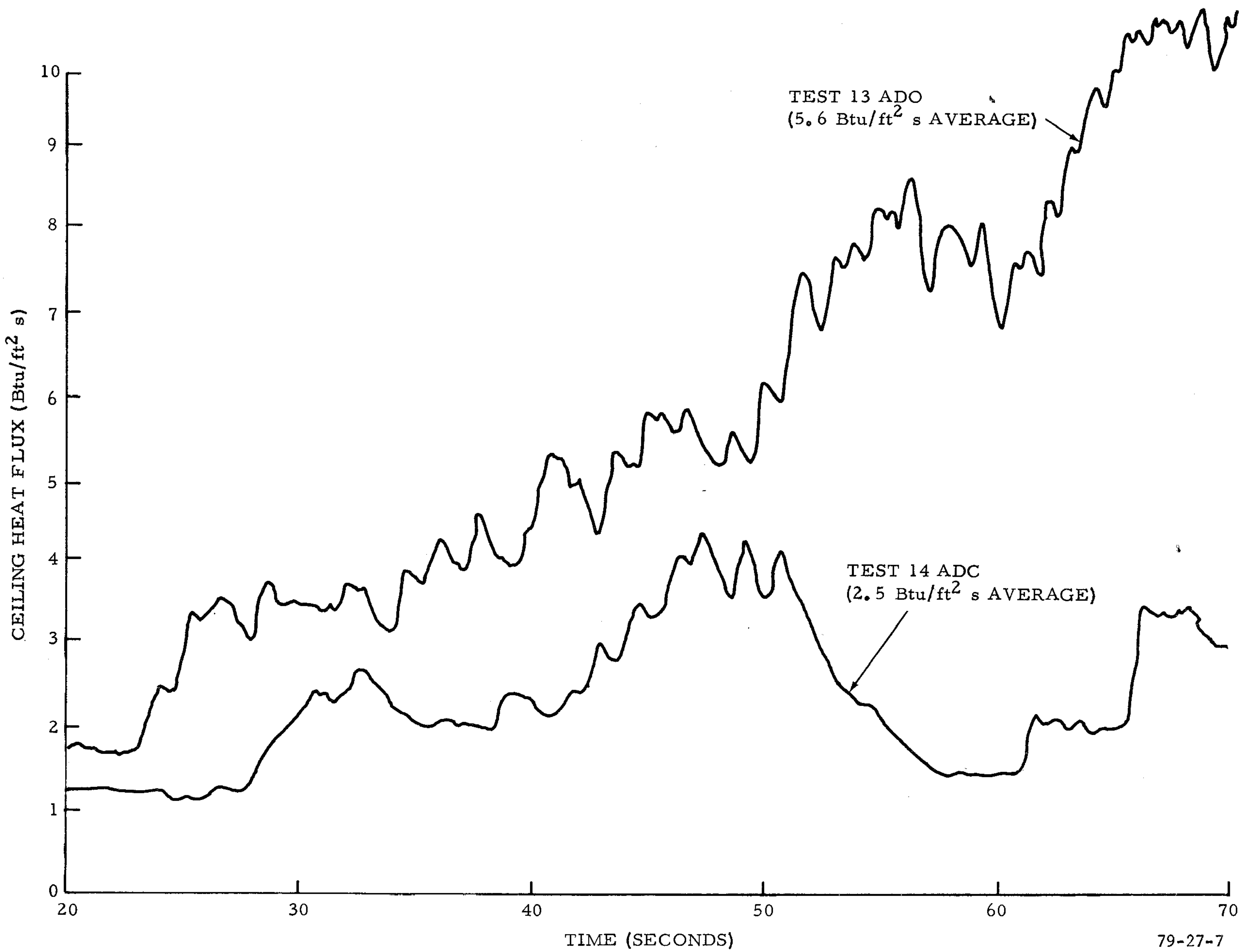

FIGURE 7. CEILING HEAT FLUX UNDER CALM WIND CONDITIONS--TESTS 13 AND 14